

PROBLEMS OF QUALITY

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REASONS FOR DEFECTS IN ALUMINUM MIRRORS ON SILICATE GLASS

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The reasons for the formation of defects in producing mirrors in a VATT 1600-3M spraying set are analyzed. Recommendation for upgrading the set and the spraying process are given.

Magnetron systems are spraying systems of the diode type, in which a material is sprayed by means of bombarding the surface by ions of the working gas (usually argon), which are formed in the plasma of an anomalous glow discharge. The high spraying rate typical of these systems is reached due to increased ionic current density, as a consequence of plasma localization near the sprayed target surface using an intense cross magnetic field [1]. The VATT 1600-3M set (produced by Ferri-watt JSC, Kazan) is intended for spraying large-sized mirrors. The spray chamber contains three magnetrons of the spraying system, and between them a glass sheet is placed to deposit the mirror layer. Rarefaction inside the chamber is developed by a forevacuum pump and three oil-vapor diffusion pumps (up to 10^{-5} Torr). The sprayed target is a cathode moving along the glass surface. The second electrode is the body of the spraying chamber. The glass sheet is fixed separately from the chamber body. The target is aluminum or an alloy with a high aluminum content.

The prerequisites for producing high-quality mirrors include the absence of dust and hydrocarbons in the residual atmosphere, appropriately selected operating conditions of the magnetrons, and protection of the deposited mirror layer from external effects. The effect of the residual atmosphere on the glass quality was investigated earlier [2, 3]. The purpose of the present study was to analyze the effect of the target composition, the operating conditions of the magnetrons, and the self-adhesive decorative film on the quality and durability of mirrors.

The experimental results were obtained using an ÉS-2401 x-ray-electron spectrometer and an MS-7210 mass spectrometer.

The idea of replacing costly aluminum by less expensive aluminum-bearing alloys is attractive; however, this can result in the emergence of defects on the mirror coating.

We investigated mirrors spray-deposited using a target made from the D16 alloy that contains (here and elsewhere in wt.%): 1.08 Cu, 4.00 Mg, 0.41 Mn, 1.05 Fe, 1.00 Si). Alloys of this grade are widely used in industry. To improve their strength properties, they are subjected to artificial aging after hardening. The aging of the alloy consists in the formation of disperse particles, which differ in their elemental and phase composition from the matrix composition. The purpose of these particles is dispersion strengthening. The formation of disperse particles is accompanied by depleting the alloy matrix of the doping elements. Similar processes are observed in natural aging of alloys.

An x-ray structural analysis of the alloy used as the target was carried out using a DRON-3M diffractometer with copper radiation. The aluminum matrix (92.5%) contained phases of MgCuAl_2 (4.0%), $\text{Cu}_{13}\text{Al}_2\text{Mg}_{10}$ (1.4%), AlCu_3 (1.6%), and iron-bearing phases (less than 1.0%). Different compositions are characterized by different spraying rates and different melting and vaporization temperatures. As a consequence, a very extended surface with a peak-cavity relief is formed, and defects in the form of small and large lustrous dots are visible on the mirror surface. The central part of a large defect is optically more transparent and resembles in its shape a drop falling at a certain angle onto the surface, with small droplets scattered around.

The defects shaped as small lustrous dots have a semi-spherical shape and clearly defined optically opaque contours. After etching in an alkali solution (20% solution of KOH), a crater remains instead of the dot. The composition of the defects was investigated using the methods of secondary ionic spectrometry and Auger-electron spectroscopy. The defect-free mirror surface visually has a heterogeneous composition: one can distinguish areas of pure aluminum and areas with an increased quantity of magnesium, manganese, iron, and copper. The large defects constitute an alumi-

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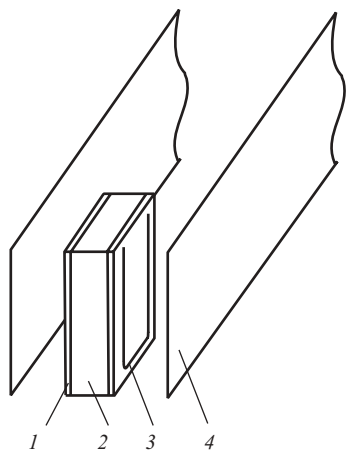


Fig. 1. Scheme of spraying of a mirror layer on glass in the VATT 1600-3M set: 1) cathode (target); 2) magnetic system; 3) anode; 4) glass for mirror spraying.

num matrix enriched with iron and manganese. Heterogeneity of the composition is found even within a single defect.

The defects are nonuniformly distributed over the mirror surface: the largest quantity is observed along the glass edge on the site of the magnetrons lighting up and on the opposite side. The number of defects is correlated with the magnetron operating conditions in the following way:

- as the strength of current of lighting up the magnetron decreases from 20 to 15 A, the number of small defects increases and the number of large defects decreases;
- an increase in the operating current from 12 to 14 A leads to insignificant growth of the number of defects;
- an increased number of runs of the magnetron along the mirror in spraying with a current strength equal to 12 A causes an insignificant decrease in the number of lustrous dots.

Another defect related to the operation of the magnetron is represented by dark stripes along the edges and in the center of the mirror. One of the reasons for this defect is dust loading of the mirror insulators. This effect is observed already after several spraying cycles and as a consequence, breakdown occurs through the mirror to the chamber body. It is necessary to provide protective screens for the insulators; moreover, these screens should be made from the target material, since they get heated in operation and may become partly sprayed. The use of steel screens leads to the formation of dark spots and stripes on the mirror surface, in which molybdenum, iron, and other elements contained in steel are identified.

The use of the spray chamber body in the capacity of an anode ought to be recognized as an unfortunate design solution. In this case dust, hydrocarbons, and other contaminants inevitably penetrating into the chamber during the insertion of glass and adsorbed on the chamber walls impair the composition of the mirror coating.

Figure 1 shows an upgraded variant of the spraying set, in which the anode is insulated from the body. To decrease the probability of oil penetrating from the pumps into the vacuum pipelines, foreballoons and traps are usually installed in such sets. It is recommended to feed air into the chamber through a filter [4].

To protect the spray-deposited mirror layer from mechanical and other external effects, a protective coating is deposited on it, which has to meet the following requirements:

- full tightness and impermeability to air and moisture;
- mechanical strength;
- when mirror glass is being cut, the protective coating film should break off together with the glass exactly along the cutting line;
- good adhesion to the mirror layer;
- absence of chemical reactions with the metal of the mirror layer.

The service life of mirrors to a large extent depends on the quality of protective coatings.

A two-layer coating is traditionally used to protect the mirror layer [5]. The base layer, i.e., the first protective layer is usually a phenol varnish or a mixture of red lead with natural drying oil. The second protective layer of the coating deposited on top of the first layer is made from asphalt-bitumen or bakelite varnish.

The application of protective coatings involves certain difficulties, since it requires a separate room, exhaust systems, and drying facilities or drying shelves. Consequently, some companies have started using self-adhesive decorative films to protect the mirror layer. These films are sufficiently hermetic and a protected mirror layer does not change even after 40 min of boiling in tap water. When mirror glass is cut, the film breaks off together with the glass exactly along the cutting line and has good adhesion to the mirror layer.

However, after 2 – 6 months of service certain defects were observed on some mirrors coated with the decorative film. At a magnification of $\times 50$, this defect is visible as an alternation of clear and opaque stripes radiating like ripples from the center.

Furthermore, after the film is removed, the mirror coating becomes optically more transparent, and the adhesive layer partly remains on the mirror surface. This effect is observed on mirrors that have been covered by the decorative film for 2 – 6 months. It is obvious that the adhesive layer is not inert toward the aluminum coating, since the adhesion process implies a reaction between the glue and the agglutinated surfaces. The depth of this interaction is determined by the diffusion processes, which stop when the adhesive solidifies, but may go on indefinitely in the case of contact with a glue that has a permanent adhesive capacity.

Metallic aluminum, aluminum oxide, and phases containing magnesium, copper, manganese, and iron have different reaction capacities and resistance to the adhesive layer. Therefore, the emergence of defects on mirrors spray-coated

with an aging aluminum alloy as a target is more probable than on mirrors spray-coated using an AD0 or AD1 target.

Thus, to obtain high-quality mirrors on a VATT 1600-3M spraying set, it is advisable to introduce certain modifications in the design:

- to install foreballoons at the exit from the diffusion pumps;
- to replace water-chilled traps by nitrogen traps;
- to attach a dust- and moisture-trapping filter to the air-feed valve feeding air into the spray chamber;
- to insulate the magnetron anode from the body;
- to protect the mirror insulators with screens made from the target material.

It is inadvisable to use aging alloys as targets.

It is inadvisable to use self-adhesive decorative films to protect the spray-deposited mirror layer.

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